Genetics, the Unifying Science in Biology*

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One may be excused for opening a paper on a subject of this kind by several propositions of such obvious validity that their statement is immediately recognized as platitudinous:

There is no wholly unrelated fact; all truth forms a connected fabric of inconceivably vast, indeed of infinite extent. A single observation or any number of single observations between which no connection is recognized may each and all be true, but they do not constitute science. Science consists of a body of knowledge which rests on recognizedly related observations. The relationships between observed facts are so numerous withal, and of so many different kinds that it is utterly impossible for any single individual to apprehend and comprehend more than a minute fraction of all that it is possible to know.

It has been inevitable that the curiosity, that has led men to make systematic observations in order to add new facts related to those in which their interest has been already aroused, has resulted in the sampling of many different parts of the network of observable phenomena and ascertainable relationships. Nature presents many different kinds of objects on which observations can be made, and among which relationships may be obviously present or may be discovered if sufficient attention be given to them. With so many different kinds of objects and different directions of approach there has arisen a bewildering multiplicity of scientific disciplines, which, notwithstanding their obvious overlapping and marginal merging with one another, have tended inevitably to obscure the congruity of all facts and relationships in a limitless universe.

Of the observations, cogitations, inductive and deductive reasoning in prehistoric times we know nothing but there is no reason to doubt that the human mind exercised itself in all these ways just as it does today. The history of biological science usually starts with the marvelously comprehensive work of Aristotle, but there must have been many pre-Aristotelians of exceptional intellectual capacity, whose intellectual acumen and keener-than-average powers of observation gave them high quality as individual "natural philosophers," but who, because of the lack of ready means of record and of intercommunication, made no permanent impression on subsequent progress of human knowledge and whose very existence can be only a matter of conjecture; they were the "mute, inglorious Miltons" of biological science, of whom only a few fragmentary records, if any, remain.

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* Read at the 75th Anniversary Celebration of the Torrey Botanical Club at the Brooklyn Botanic Garden, Thursday, June 25, 1942.

With the rise of recorded science came also authoritarianism,—the establishment of *"schools"* consisting of the students and followers of individual observers, thinkers and teachers. Such groups of disciples did not as a rule become independent observers, nor independent thinkers. Rather were they simple protagonists of the theories of their leaders and disputatious opponents of the divergent views of other leaders.

Not until the coming of the Renaissance, and the development of the printing-press, cheapening and making more effective the process of permanent record and of intercommunication, could there be the accumulation of the observations and of philosophical concepts and theories of many individuals which gradually built up the diversification of knowledge which characterizes the field of science as we know it today. Along with this accumulation of recorded fact and theory, arose the competitive spirit, the checking and rechecking of hypotheses by new observation, the winnowing of truth from the chaff of fallacy.

The scientific field has been enlarged by bringing new objects under observation, through exploration and importation of materials from geographical areas of ever increasing extent. Also the invention of new instruments of research—the microscope, microtome, centrifuge, galvanometer, potentiometer, Crooks tube, cyclotron, electron microscope,—and the discovery of new effective chemicals, such as indole acetic acid, thiamin, colchicine, etc., have made possible new analyses and the perception of new relationships not previously recognized. Similar expansion has come from the discovery of exceptionally favorable research organisms and structures, as, for example, the mutation phenomena, the chromosome circles, and lethal factors of *Oenothera;* the regenerative capacity and tolerance of transplantation in Amphibians; the almost limitless genetical and cytological advantages of *Drosophila* for studies on the relations between genes and chromosomes; the effectiveness of the coleoptiles of *Avena* for the recognition of growth-promoting substances; and many others. All of these have brought about so great an expansion of the field of biological science that ever closer specialization is required in order to make further progress. This situation has been long recognized and jokingly referred to as "learning more and more about less and less."

So much for the expansion and diversification of biological science. As a result the science of biology has been divided into a very large number of separate branches, now commonly referred to as the plant sciences and the animal sciences, plus those which relate about equally to both plants and animals, such as general or cellular biology, ecology, and genetics.

The specialists working in each of these biological fields have found it advantageous to organize special societies for the holding of periodical meetings and for the support of adequate means of record and publication of their discoveries.

The simplest type of scientific activity is the naming and classification of natural objects, and the first taxonomist of whom we have record was Adam, who, according to the Biblical account, had all the plants and animals of the Garden of Eden brought before him to receive their names. How natural that the reawakening of human intelligence in the Renaissance should have been characterized by the rise of taxonomy, the "mother" of all the biological sciences! A very substantial contribution to the unification of the biological sciences was the adoption of the binomial system of nomenclature and its very extensive applications to both plants and animals by Carl Linné in the middle of the 18th century.

The more philosophical phases of classification which came to recognize natural relationships between genera, between families, and between groups of still higher order developed more gradually and at the hands of an ever increasing number of workers, both zoologists and botanists. On both sides it was soon recognized that in one important corner of the taxonomic field plant taxonomy and animal taxonomy overlap each other, so that *Euglena*, the Myxomycetes *alias* Mycetozoa, and the Volvocineae, for example, have been equally claimed by both plant and animal taxonomists.

Another discovery of the greatest importance for the unification of biological science was the recognition, independently and then jointly arrived at by Schleiden and Schwann in 1839, that both plant and animal bodies are made up of cells and substances and structures secreted by cells. This great generalization grew rapidly in importance as refined microscopical technique brought to light ever finer details of intra-cellular organization without finding a single consistent difference between plant and animal cells, either in the structures they contain or in their physiological activities.

These discoveries gave rise to the concept of biology as a single discipline, especially through the writings and teachings of Thomas Huxley, Herbert Spencer, John Tyndall and others. These writers emphasized the many common features of plants and animals, which made possible the stratification of biological knowledge in fields at right angles to the taxonomic line of division between the two Kingdoms; thus tying them together by bonds more natural than the divisions themselves between the Kingdoms. The principles of organography, tissue-differentiations, competition and cooperation of parts, specialization of tissues and the accompanying division of labor are equally applicable to and derivable from plants and animals, as are all the fundamental physiological processes, like nutrition, assimilation, growth, respiration, excretion and reproduction.

With the development of the evolution hypothesis in the first half of the last century and its gradual acceptance by all biologists, the fact that so many major fields of biology could bring supporting evidence, gave a still stronger bond of unity among the several branches of biological science. Taxonomy, comparative anatomy, embryology and paleontology were the chief sources of this supporting evidence.

It remained to secure convincing evidence of the evolutionary processes from actual experimentation, and here we can not over-stress the indebtedness of the entire biological world to that great genius of simplicity, philosophical outlook, penetrating vision and energetic persistent labor, Hugo de Vries, whose work more than that of any other individual ushered in a new era in biological science and philosophy. Thus was born the new experimental science appropriately called for a time "experimental evolution," but felicitously christened by William Bateson in 1906, the science of "Genetics." Inter-relationships of plant groups and of animal groups took on a new and more fundamental meaning when analyzed by the simple means provided by the experiments of Mendel and De Vries. There came in this way a clarification of concepts, and the possibility of brushing aside fallacious doctrines and their replacement by experimentally tested facts.

From another direction came independently another fundamental element of genetical technology. Contemporaneous with the work of Mendel and of De Vries was the statistical attack on problems of evolution, brilliantly conceived and put into practice by Sir Francis Galton, a cousin of Charles Darwin. This was the technique of the mathematical analysis of populations later denominated "Biometry."

Although Galton's conclusions seemed at first to be at variance with the discoveries of Mendel, the work of the genial and brilliant Danish plant physiologist, W. Johannsen, on pure-lines and populations in beans disclosed the nature of the discrepancy and brought complete harmony between the observations of Galton and those of Mendel and thus helped to establish biometry as one of the fundamental biological techniques. The tool thus developed for the handling of population problems may be considered not the least of the contributions which genetics has made to the other sciences, most of which tend to become more and more statistical as their stores of basic materials grow in magnitude and diversity.

One of the most important discoveries which resulted from the experiments of De Vries was the demonstration that variations, which Darwin had taken for granted and had assumed to be more or less generally transmitted from parents to offspring, are of two kinds. Some are completely inherited and remain permanent elements of organization in subsequent generations while others are non-inheritable and promptly disappear from subsequent generations. This important differentiation of variations into inherited and non-inherited, respectively designated "mutations" and "fluctuations," was beautifully and convincingly confirmed by Johannsen, whose keen analytical mind gave the new science of genetics its sharply accurate terminology. Inherited variations involve permanent changes in the genotype while the impermanent ones involve changes in reaction of this permanent genotype under changed environmental experiences. Only genotypic changes can have immediate and direct importance for evolutionary progress, although the capacity of a single genotype to react in different ways in response to changed environments may be of crucial importance in determining the survival of the genotype in question in relation to its competitors in the "struggle for existence."

Because of certain technical advantages of plants for genetical studies, especially the facility they have for self-fertilization, Mendel's laws were worked out with garden peas, and all of the three nearly simultaneously published papers of De Vries, Correns and Tschermak were based on experiments with plants; but work by L. Cuenot with mice, of Bateson and his distinguished coterie of collaborators with poultry and canaries, of Long with snails, of Castle with guinea-pigs, rats and rabbits and Davenport with poultry, canaries and with studies of human families, quickly showed that animals as well as plants follow identical patterns of genetical behavior.

The simplicity of the pedigree-culture methods and the fundamental importance of the facts and principles to be derived from the utilization of these methods, resulted in a very prompt participation of many investigators who in many cases abandoned for the time being the important fields of their previous interest to become the founders of the science of Genetics as we know it today. I have already mentioned in this connection the plant physiologist Johannsen and the animal morphologist and comparative anatomist Bateson. To these should be added the statisticians, Galton, Pearson and Davenport, embryologists such as Morgan and Conklin, and cytologists like E. B. Wilson, C. E. McClung and Calvin Bridges, to mention only a few of the more outstanding examples.

In this way there has grown a body of knowledge of plant and animal organization of astounding magnitude in the brief period of four decades. There has also been demonstrated a meticulous consistency of all of the phenomena which have been brought to light by these methods applied to both plants and animals. This consistency stresses a closeness of kinship of all living things, which hardly could have been dreamed of before the demonstration of the genes as the elements of organization of living matter.

The genetical approach has served to bring into harmony many phenomena of plant and animal organization and behavior which previously had had seemingly few points in common. For example the whole field of sex relationship has been greatly clarified through recognition of its basic relationship to genetical phenomena. Mendelian heredity was soon recognized as the product of the two critical phenomena which lie at the base of all sex, namely, the phenomena of diploidization through the union of egg and sperm, and haploidization brought about by meiosis, the "reduction division." The unfortunate confusion of terminology in botanical and zoological literature in relation to sex phenomena is still only partially resolved but there can be little doubt that a common and concordant terminology will be ultimately achieved through the influence of genetical considerations. The confusion began when botanists took over the sex terms which had been long applied by zoologists and by laymen,—by the botanists themselves,—in regard to diploid animals and applied them to the haploid generation in plants which has no counterpart in animals.

To achieve complete harmony it is necessary only to limit the concept of sex-homologies between plants and animals, to the diploid generation of plants, since it is the "sporophyte" of the higher plants that manifests Mendelian phenomena in exact agreement with those exhibited by the bodies of animals. The situation becomes clear if we take as the starting point for a comparison of the life-cycle of plants and animals the moment of union between egg and sperm. This brings the diploid resting-spore of the Chlorophyceae into a position of homology with the body of an animal, and leads to recognition of the fact that the fundamental difference between embryophytes and animals is the fact that in the former, the ootids (megaspores) and the spermatids (microspores) develop parthenogenetically to form respectively the female and male gametophyte generations, whereas in animals they are converted as a rule directly into eggs and sperms.

The closest relationship of genetics with the other biological disciplines is that between genetics and cytology. Before the birth of genetics, cytology had its major outlook directed toward comparative embryology. With the specific recognition of the chromosomes as the determining mechanism of the Mendelian phenomena, it has become obvious that cytology and genetics jointly constitute the biology of the chromosome. Cytology represents the morphological phase and genetics the physiological phase of the inheriting mechanism, but the relationship is so close that it is frequently indicated by the use of the term "cytogenetics" for this very fundamental scientific discipline.

In all other branches of biological science,—taxonomical, morphological, physiological, sociological, psychological,—the fact is of fundamental significance that genes constitute the basic material with which the researches in these several fields must deal. The origin and distribution of genes generally follow a pattern of very great simplicity which must be taken into account in laying out programs of experimentation, in analyzing the results of such experiments, and in drawing tenable conclusions from them. Genetics, the science of kinship, thus knits together, even to the most intimate details of basic organization, the organisms with which every phase of biological science deals, and strongly emphasizes the inherent kinship of all branches of biology.

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